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(54) **RECIPROCATING PUMP CAVITATION DETECTION AND AVOIDANCE**

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(22) Filed: **Aug. 12, 2014**

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F04B 51/00 (2006.01)
F04B 49/06 (2006.01)

(52) **U.S. Cl.**
CPC ***F04B 51/00*** (2013.01); ***F04B 49/065*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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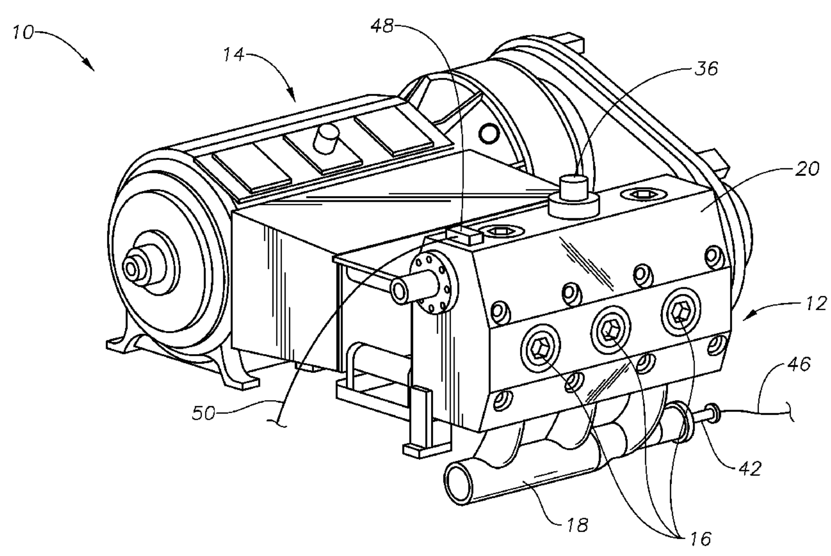
(57) **ABSTRACT**

Systems and methods for detecting cavitation in a reciprocating positive displacement pump. Fluid pressure proximate the pump's suction manifold is compared to a predetermined pressure that would be conducive to cavitation. If the detected pressure approximates the predetermined pressure, the presence of cavitation is confirmed via correlation of increased vibration.

15 Claims, 8 Drawing Sheets



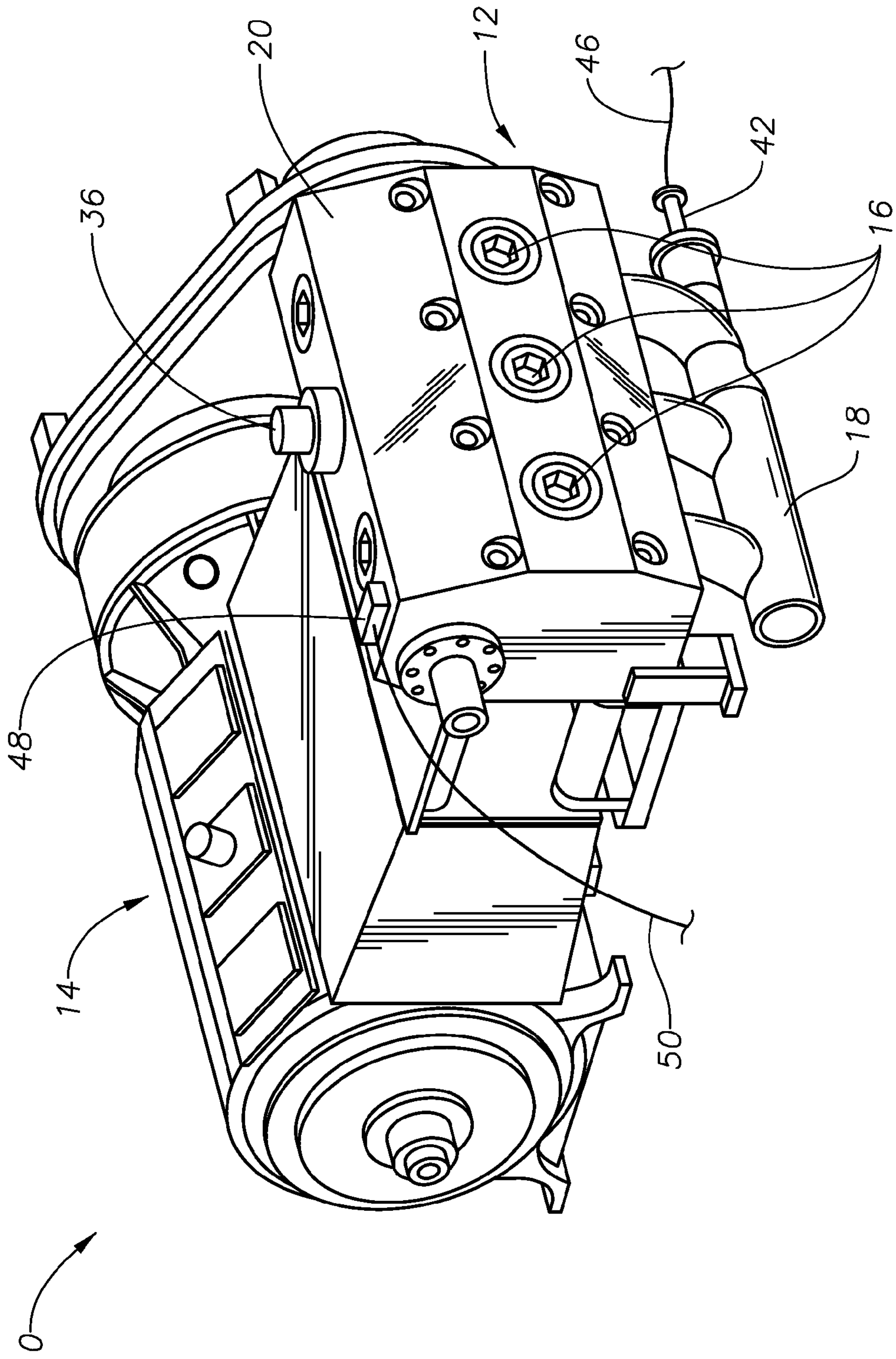


FIG. 1

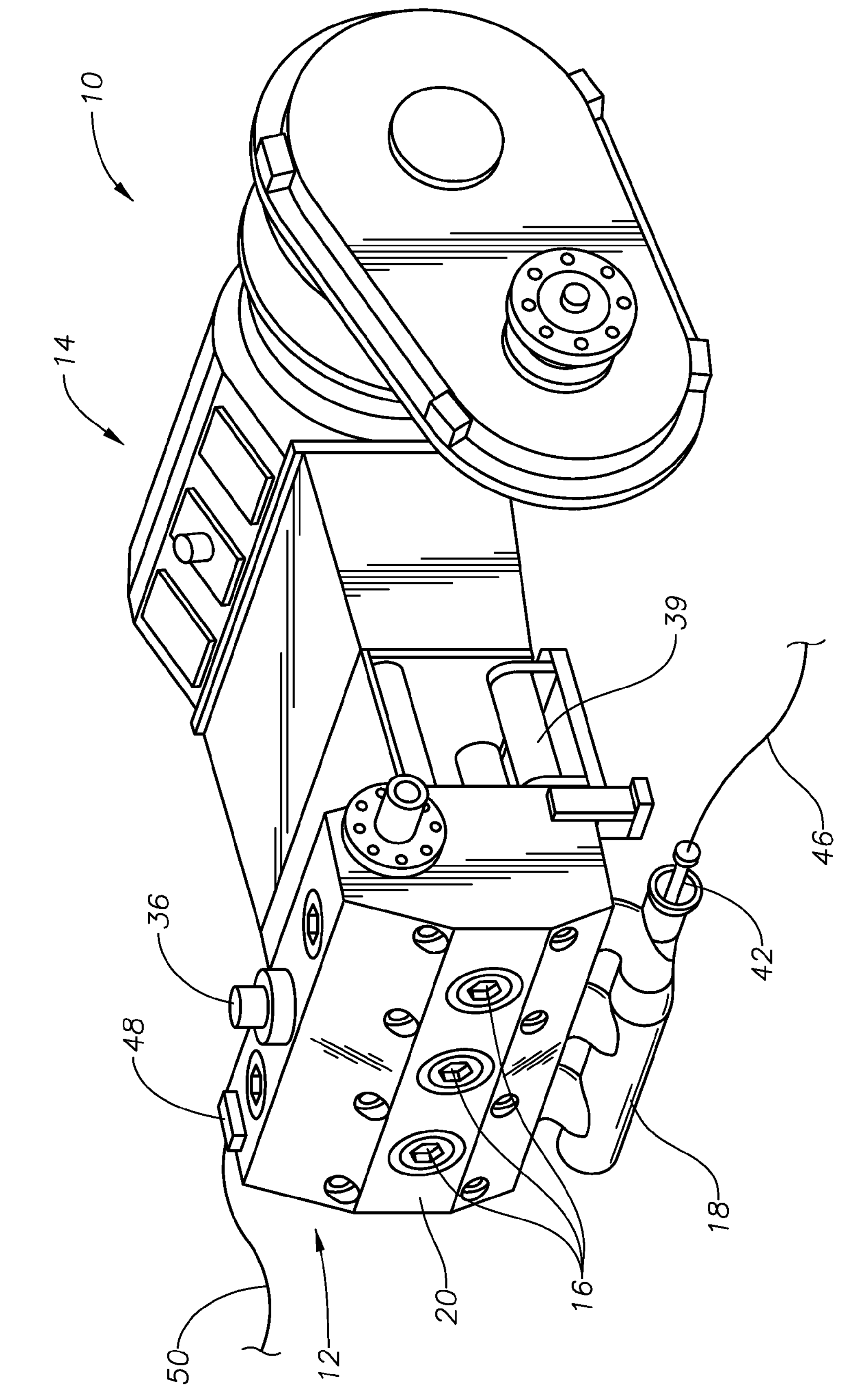


FIG. 2

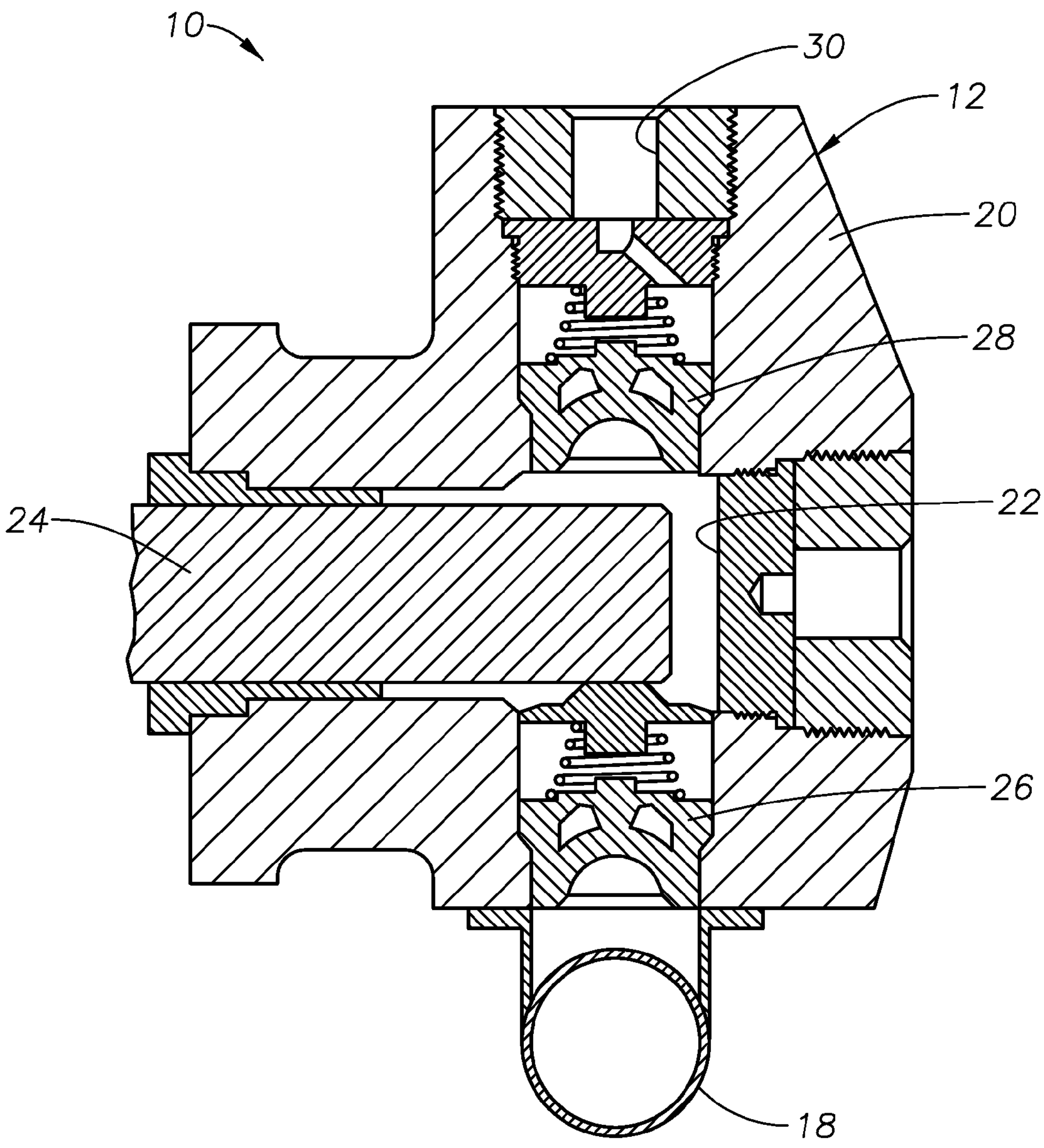


FIG. 3

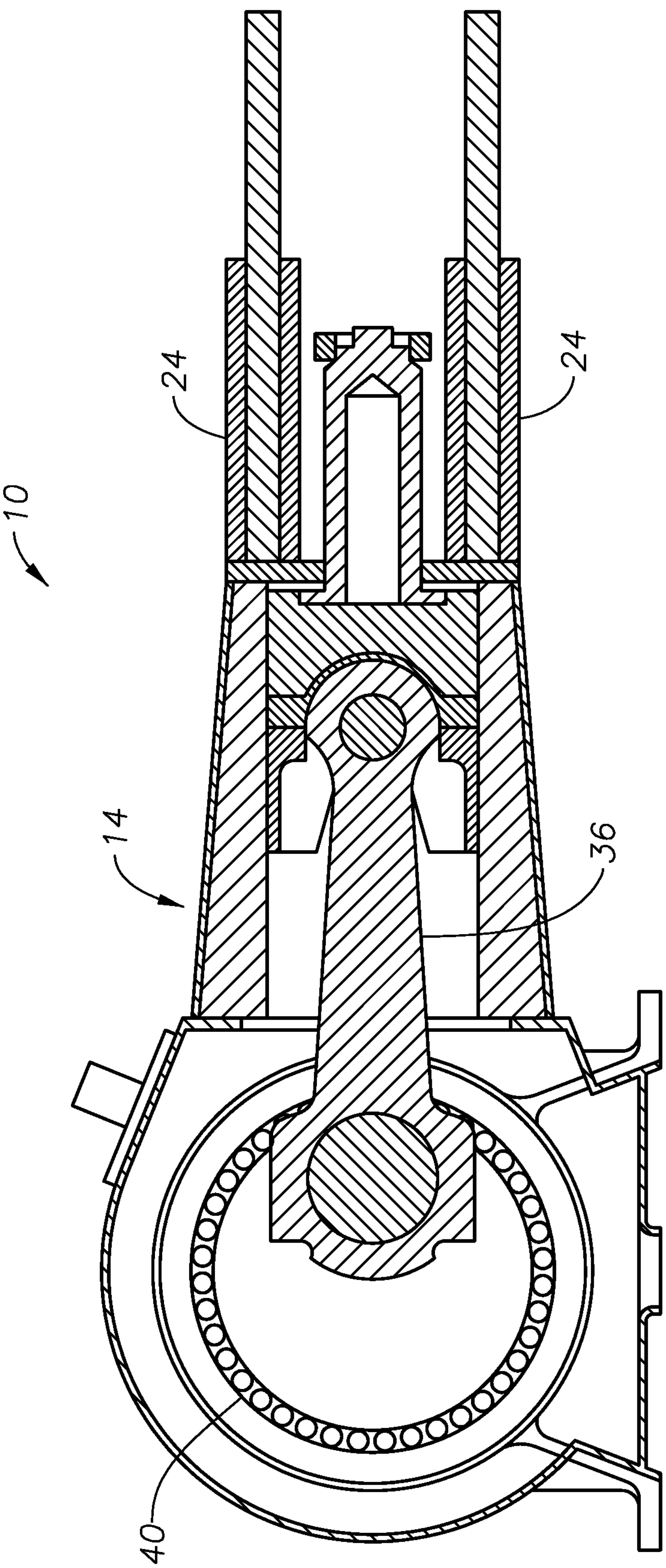


FIG. 4

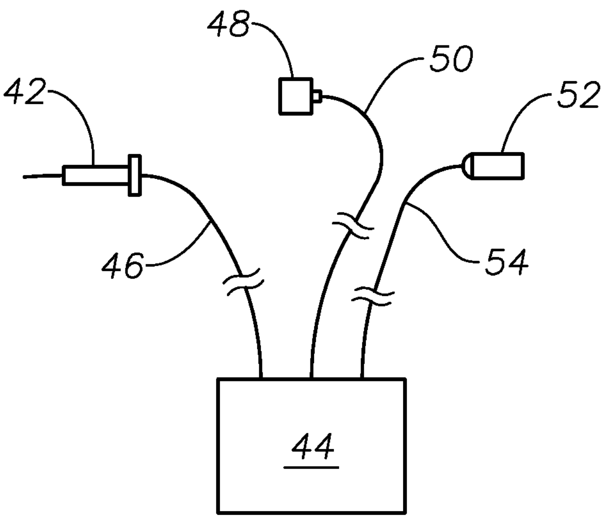


FIG. 5

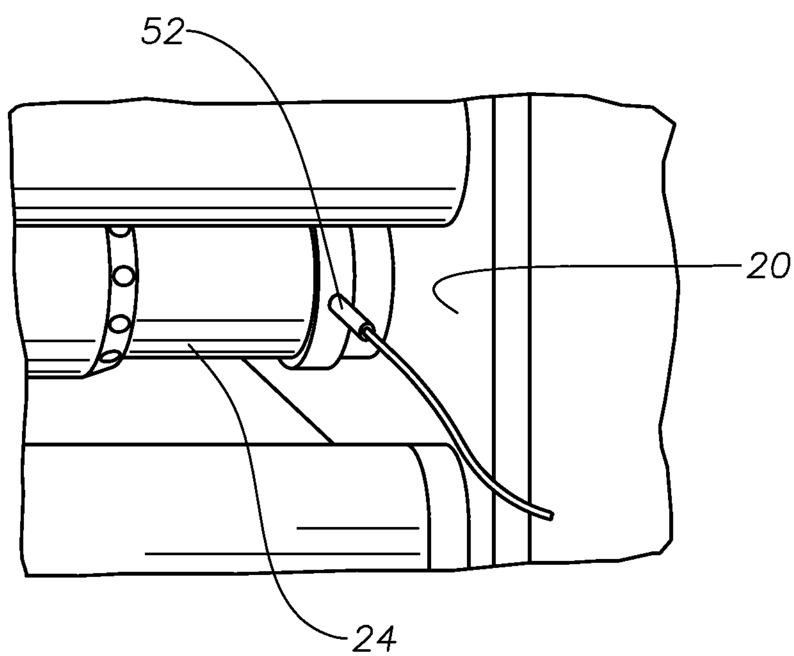


FIG. 6

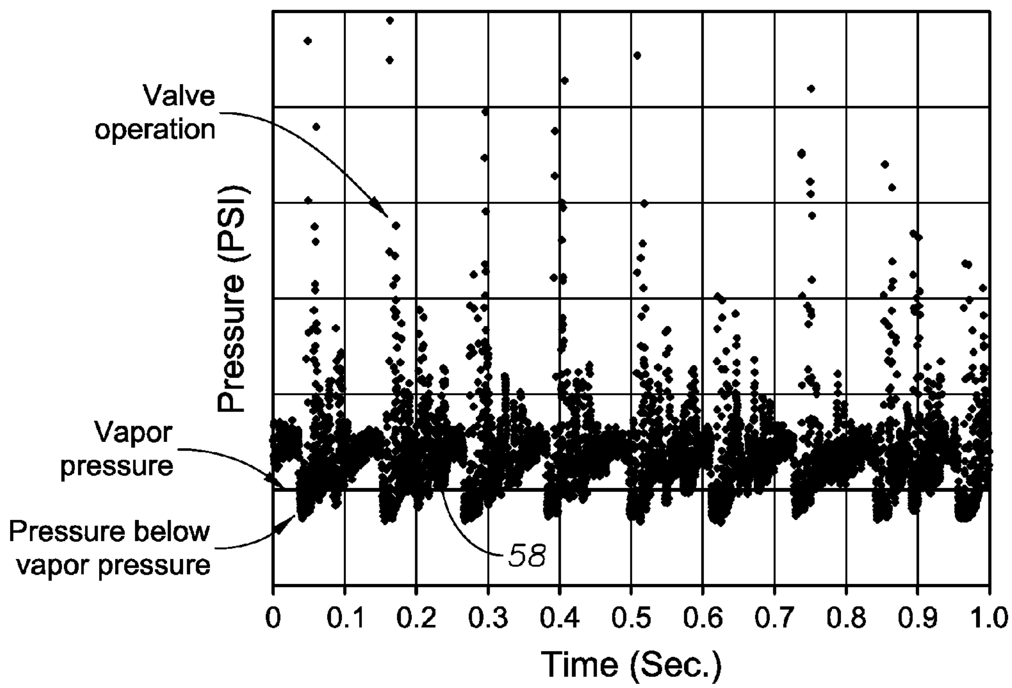

Valve
operation
Vapor
pressure
Pressure below
vapor pressure
58
Pressure (PSI)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time (Sec.)

FIG. 7

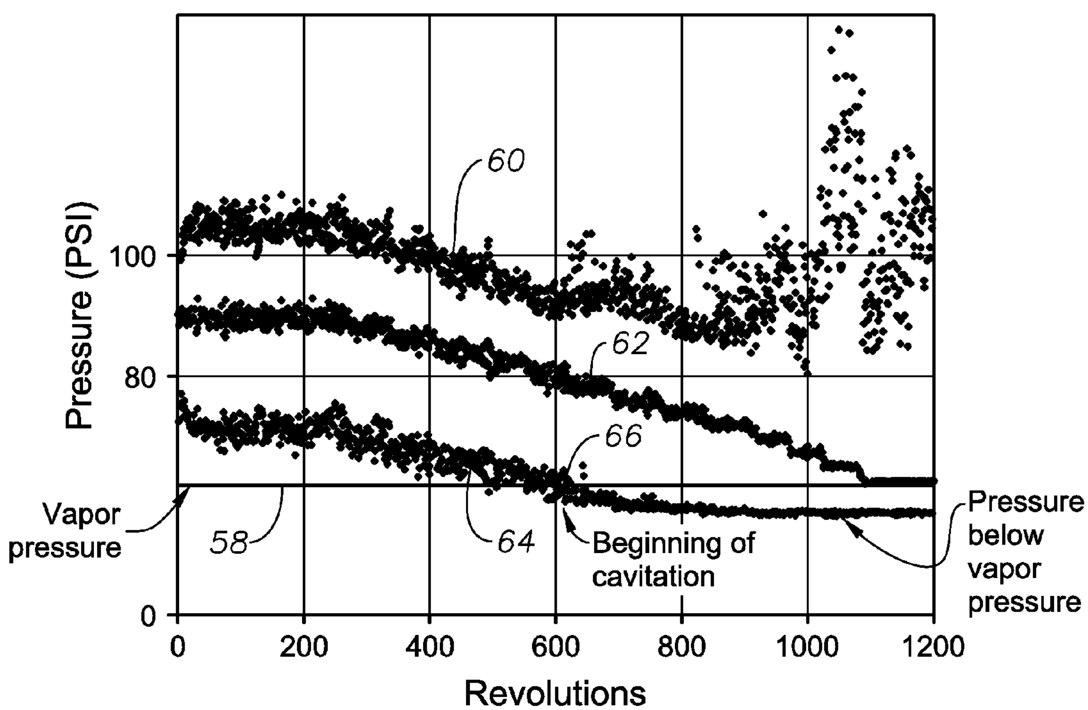

60
62
66
64
58
Vapor
pressure
Beginning of
cavitation
Pressure
below
vapor
pressure
Pressure (PSI)
100
80
0
0
200
400
600
800
1000
1200
Revolutions

FIG. 8

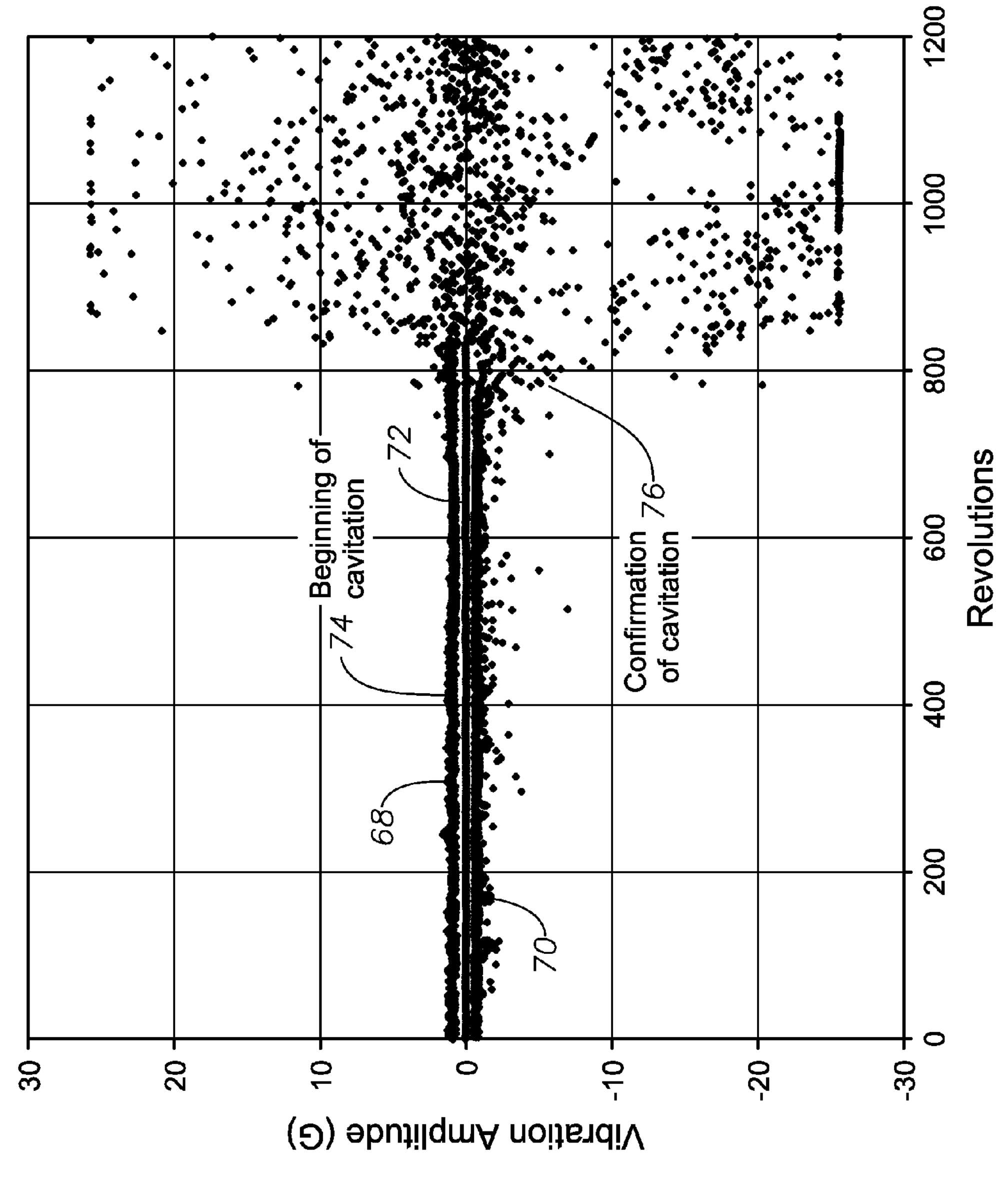

Vibration Amplitude (G)
30
20
10
0
-10
-20
-30
Revolutions
0
200
400
600
800
1000
1200
Beginning of cavitation
Confirmation of cavitation
68
70
72
74
76

FIG. 9

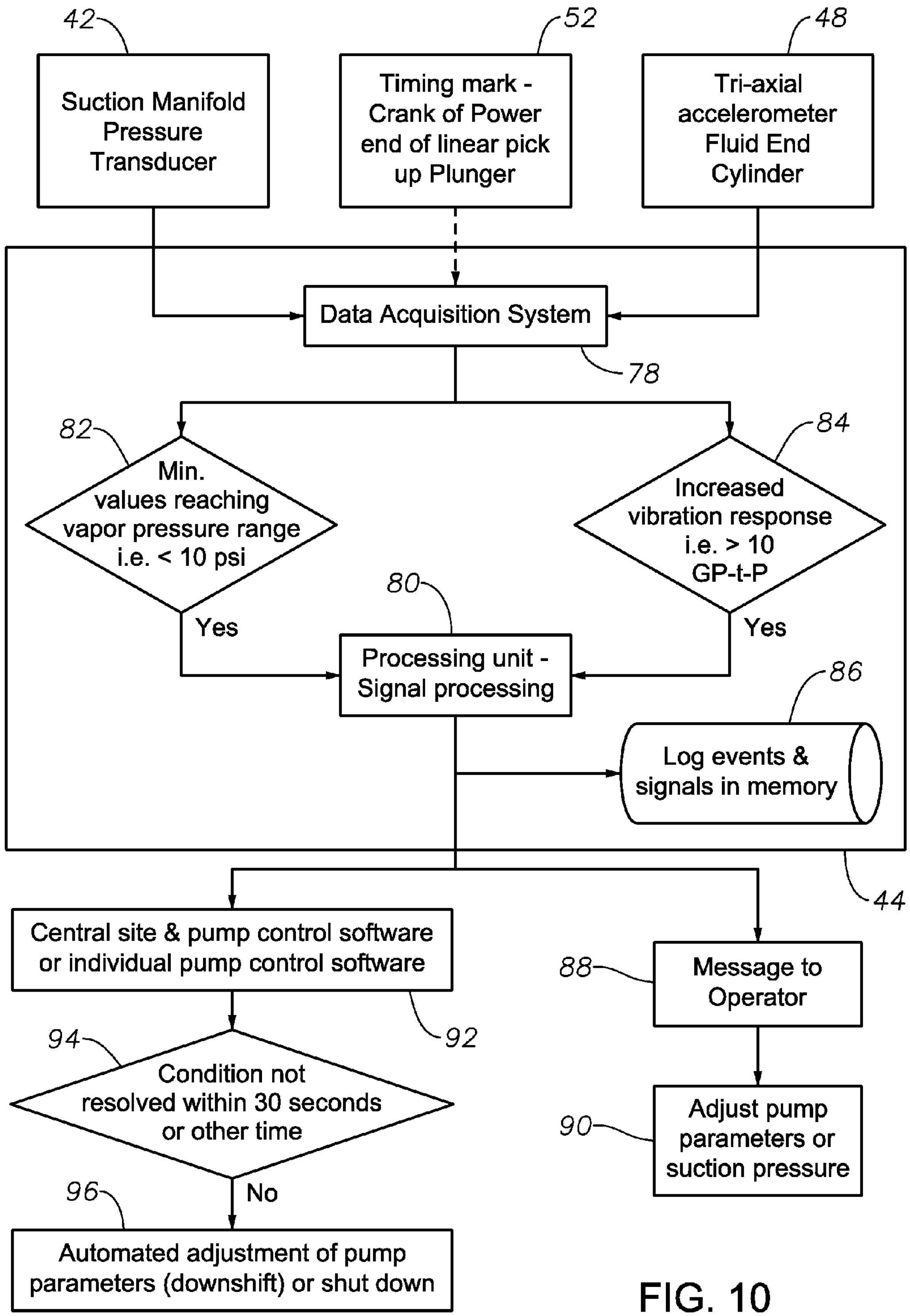

42
Suction Manifold Pressure Transducer
52
Timing mark - Crank of Power end of linear pick up Plunger
48
Tri-axial accelerometer Fluid End Cylinder
Data Acquisition System
78
82
Min. values reaching vapor pressure range i.e. < 10 psi
84
Increased vibration response i.e. > 10 GP-t-P
Yes
80
Processing unit - Signal processing
Yes
86
Log events & signals in memory
44
Central site & pump control software or individual pump control software
92
88
Message to Operator
94
Condition not resolved within 30 seconds or other time
90
Adjust pump parameters or suction pressure
No
96
Automated adjustment of pump parameters (downshift) or shut down

FIG. 10

RECIPROCATING PUMP CAVITATION DETECTION AND AVOIDANCE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to reciprocating pumps. In particular aspects, the invention relates to systems and methods for detecting and monitoring abnormal conditions within a pump, including cavitation.

2. Description of the Related Art

Reciprocating positive displacement pumps used in the well service industry and drilling mud pump industry are exposed to high pressure, high flow rate and abrasive fluids (slurry) for the purpose of fracturing, drilling and so forth. Reciprocating pumps can be single or double acting pumps with pistons that are driven by a crankshaft that is actuated by a motor. Reciprocating positive displacement pumps have at least one piston cylinder, but often have multiple cylinders, such as three-cylinder (triplex) and five-cylinder (quintuplex) configurations.

Cavitation affects reciprocating pumps during operation. Cavitation occurs when actual pressure reaches the vapor pressure of the fluid being pumped, and the fluid starts to vaporize. Small vapor bubbles are formed and, under compression, will implode. If these implosions occur in close proximity to the pump housings or valve surfaces, they will start to impinge the material, causing material to be removed and damaged. Cavitation can cause permanent damage and, if not prevented in time, can lead to complete destruction of the pump housing and/or associated components.

Efforts have been made to identify cavitation in an operating pump using acoustic signal analysis. However, this has proven problematic. There is a wide variety of vibration or acoustic signal responses that relate to a variety of abnormal conditions, which makes it difficult to differentiate between cavitation, valve wear, seal failure, or other conditions.

SUMMARY OF THE INVENTION

The invention provides systems and methods for detection of cavitation within a reciprocating pump. In certain aspects, the systems and methods of the present invention permit detection of cavitation with particularity so that other abnormal conditions may be excluded.

In a described embodiment, a sensor is used to detect fluid pressure within or proximate the suction or intake manifold of the pump. An accelerometer is disposed on the fluid end cylinder housing of the pump for detection of vibration. A timing marker is operably associated with a plunger of the pump and detect the speed of operation of the pump.

Actual fluid pressure detected at or near the suction manifold is compared to a predetermined pressure which would be conducive to cavitation. In particular embodiments, the predetermined pressure is the vapor pressure for the fluid being pumped by the pump **10**.

The accelerometer is monitored to detect an increase is vibration or shocks. An increase in vibration/shocks is correlated with the condition of the measured pressure approximating the predetermined pressure. This correlation indicates cavitation.

In accordance with currently preferred embodiments, a data processor receives data signals from the pressure sensor, accelerometer and timing marker which are indicative of the parameters being sensed by those components. The data processor then compares the detected pressure with a predetermined pressure (i.e., vapor pressure) and checks for cavitation. If the processor determines that cavitation is occurring, it can then take one or more actions in response. These actions include providing a message to an operator and automated adjustment of pump parameters to attempt to correct the cavitation.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages and further aspects of the invention will be readily appreciated by those of ordinary skill in the art as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference characters designate like or similar elements throughout the several figures of the drawing and wherein:

FIG. **1** is an external, isometric view of an exemplary reciprocating pump having a cavitation detection system in accordance with the present invention.

FIG. **2** is a further external, isometric view of the pump shown in FIG. **1**.

FIG. **3** is a cross-sectional view of the fluid end of the pump.

FIG. **4** is a cross-sectional view of portions of the power end of the pump.

FIG. **5** is a schematic diagram of portions of an exemplary pump monitoring system which includes a data processor and associated components.

FIG. **6** is an enlarged external, isometric view of portions of the reciprocating pump shown in FIGS. **1-4**.

FIG. **7** is a data plot depicting fluid pressure measurements for the suction manifold during pump operation.

FIG. **8** is a data plot of transformed suction pressure data showing the beginning of cavitation.

FIG. **9** is a data plot of detected pump vibration.

FIG. **10** is a logic diagram for an exemplary pump monitoring system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1-4** illustrate an exemplary reciprocating pump **10** which broadly includes a fluid end **12**, which draws fluid into the pump **10** and expels it, and a power end **14**, which receives power from an associated motor or other prime mover and transmits this power to the fluid end **12**. In the depicted embodiment, the pump **10** is a triplex pump having three pistons, which are evidenced by the cylinder heads **16** in FIGS. **1-2**. A suction manifold **18** leads into the fluid end **12** of the pump **10**.

The cross-sectional view of FIG. **3** illustrates a cylinder housing **20** for the fluid end **12** which encloses a valve piston chamber **22** within which a plunger **24** is axially moveable in a reciprocating manner, as driven by a crankshaft. Although only a single plunger **24** is visible in FIG. **3**, it should be understood that there are actually three plungers **24** within the housing **20**. This reciprocating movement causes an intake valve **26** and an exhaust valve **28** to be opened and closed as fluid is pumped from the suction manifold **18** to the discharge **30**.

The general construction and operation of reciprocating pumps is well understood and will not be detailed here. It is noted, however, that the plunger(s) **24** is/are driven by the power end **14**, depicted in FIG. **4**, which includes a crankshaft **36** and axially moveable plungers **24** which are driven by a drive train **40**. Each full rotational cycle of the crankshaft **36** is considered to be a revolution of the pump **10**. The suction manifold **18** is constantly fed with the fluid medium to be pumped. A minimum level of energy should be constantly kept inside the suction manifold **18**, which is normally accomplished by maintaining a sufficient minimum flow rate and supply pressure.

A pressure transducer **42** (FIGS. **1-2**) is operably associated with the suction manifold **18**. The pressure transducer **42** is also operably associated with a data processor **44** via transmission medium **46**. It is noted that, while transmission medium **46** is depicted as being an electrical cable, wireless transmission, of types known in the art, could also be used. The pressure transducer **42** is adapted to detect fluid pressure within the suction manifold **18** and transmit a signal representative of the detected pressure to the data processor **44**. FIG. **5** is a schematic illustration of portions of a pump monitoring system in accordance with the present invention which includes a data processor **44** and pressure transducer **42**.

An accelerometer **48** is mounted upon or otherwise operably associated with the fluid end cylinder housing **20**, as illustrated in FIGS. **1-2**. The accelerometer **48** is preferably a three-axis accelerometer and is designed to measure vibration of the cylinder housing **20** and provide a signal representative of detected vibration via transmission medium **50** to the data processor **44**.

A timing marker **52** is operably associated with plunger **24**. If there are multiple plungers **24**, only a single plunger need have a timing marker **52**. The timing marker **52** is operable to provide an indication of the speed of operation of the pump **10** by detecting movement of the plunger **24**. This speed measurement is transmitted to the data processor **44** via transmission medium **54**. In accordance with an alternative embodiment, the speed of the pump **10** is obtained by a rotational pick-up sensor (not shown), of a type known in the art, at the power end **14** of the pump **10**.

The data processor **44** is programmed to receive data from each of the pressure sensor **42**, accelerometer **48** and the timing marker **52** (or rotational pick up sensor). In particular embodiments, the processor **44** compares the fluid pressure detected by the pressure transducer **42** with a preprogrammed pressure which corresponds to the vapor pressure of the fluid being pumped by the pump **10**. When the detected fluid pressure approximates the vapor pressure, this condition is conducive to cavitation. In accordance with preferred embodiments, the processor **44** correlates the presence of a detected-pressure-approximating-vapor-pressure condition with an increase in vibration, as detected by the accelerometer **48**. A correlation of these two conditions will indicate the presence of cavitation in the pump **10**. In addition, the inventors have determined that such a correlation in increased vibration indicates cavitation to the exclusion of other abnormal pump conditions. Pressure and vibration per revolution (as measured by the timing marker **52**) is done to detect cavitation. Preferably, the sensors provide measurements on a continuous basis, and the speed measurement provided by the timing marker **52** allows the continuous signals to be divided on a per revolution basis.

FIGS. **7-9** depict exemplary data measurements which might be obtained by a pump monitoring system in accordance with the present invention and illustrates detection of cavitation in a pump. FIG. **7** is a data plot showing suction pressure within the manifold **18** as detected by the pressure sensor **42**. It can be seen that the detected pressure rises and falls over time as the intake valve **26** opens and closes. In the depicted plot, the vapor pressure of the fluid being pumped by the pump is represented by the line **58**. Data plot points below the line **58** are indicative of the detected pressure being below vapor pressure while those points above the line **58** are above vapor pressure. FIG. **8** depicts transformed suction pressure data, with detected pressure being plotted against pump revolutions. Plot points **60** represent maximum pressure readings during each revolution of the pump **10**. Plot points **62** are average pressure readings per revolution while plot points **64** are minimum pressure reading per revolution. It is possible to detect when minimum suction pressure **64** is below vapor pressure consistently (more than **25** cycles). Point **66** represents a point where detected fluid pressure at the manifold **18** approximates vapor pressure **58** and is therefore a suspected point for the beginning of cavitation.

FIG. **9** is a data plot which depicts pump vibration amplitude, as measured by the accelerometer **48**, against pump revolutions. The upper group of data points **68** represents vibration ("G"s) in a positive direction while the lower group of points **70** represent vibration in a negative direction. Points **72** lie closest to the zero axis and represent average vibration. It can be seen from FIG. **9** that the accelerometer **48** begins to detect vibrations resulting from cavitation at or slightly after the time when pressure in the suction manifold **18** reaches vapor pressure (point **74** in FIG. **9**). FIG. **9** shows that it takes a few seconds (approximately 200 revolutions) for cavitation to cause significant vibration, which can be seen starting at about point **76**.

FIG. **10** is an exemplary logic diagram which depicts illustrative data measurement, acquisition and processing by an exemplary pump monitoring system. A data acquisition system **78** obtains measured parameters from the suction manifold pressure sensor **42**, accelerometer **48** and timing marker **52**. It is noted that the data acquisition system **78** may be contained within the general processor **44**. A processing unit **80**, which may be a programmable logic controller, then determines whether the minimum detected suction pressure (i.e., points **64**) have reached or approximate vapor pressure **58**. This occurs in step **82** in FIG. **10**. The processing unit **80** also determines (step **84**) whether there is increased vibration, as detected by the accelerometer **48** at or shortly after. If so, the processing unit **80** logs the event and signals in memory at step **86**.

Optionally, the processing unit **80** is programmed to perform one or more operations that comprise corrective actions to try to cure the cavitation problem. The processing unit **80** can send a message to an operator (step **88**) in the form of a visual or audible alarm, an electronic message or the like. This will allow the operator to adjust the pump parameters or suction pressure (step **90**) to compensate for or correct the cavitation condition. Also optionally, the processing unit **80** might execute, or cause to be executed, central site and pump control software or individual pump control software (step **92**). If the processing unit **80** then determines (step **94**) that the cavitation condition is not resolved within a particular amount of time, such as 30 seconds, pump parameters are adjusted by the software (step **96**) or the pump is shut down.

In accordance with the present invention, pump monitoring devices may be constructed which can be affixed to or located alongside a pump. These monitoring devices would include a processor **44** and the associated sensor components **42**, **48**, **52**.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention.

What is claimed is:

1. A system for detecting cavitation within a positive displacement pump, the system comprising:

a pressure sensor to detect fluid pressure at a location within the pump;

an accelerometer to detect vibration in the pump; and

a processor operably associated with the pressure sensor and accelerometer to:

compare detected fluid pressure with a predetermined pressure to determine when detected fluid pressure approximates the predetermined pressure; and

correlate detected fluid pressure with vibration when said detected fluid pressure approximates predetermined pressure to confirm the presence of cavitation.

2. The system of claim **1** wherein the pressure sensor is located to detect fluid pressure proximate a suction manifold of the pump.

3. The system of claim **1** wherein the predetermined pressure is vapor pressure for a fluid being pumped by the pump.

4. The system of claim **1** further comprising a timing marker to measure pump speed.

5. The system of claim **4** wherein the processor further correlates the detected fluid pressure and vibration with measured pump speed.

6. A system for detecting cavitation within a positive displacement pump, the system comprising:

a pressure sensor to detect fluid pressure proximate a suction manifold of the pump;

an accelerometer to detect vibration in the pump; and

a processor operably associated with the pressure sensor and accelerometer to:

compare detected fluid pressure with a predetermined pressure to determine when detected fluid pressure approximates the predetermined pressure; and

correlate detected fluid pressure with vibration when said detected fluid pressure approximates predetermined pressure to confirm the presence of cavitation.

7. The system of claim **6** wherein the predetermined pressure is vapor pressure for a fluid being pumped by the pump.

8. The system of claim **6** further comprising a timing marker to measure pump speed.

9. The system of claim **8** wherein the processor further correlates the detected fluid pressure and vibration with measured pump speed.

10. A method of detecting cavitation within a positive displacement pump, the method comprising the steps of:

detecting fluid pressure within the pump;

detecting vibration of the pump during operation of the pump;

comparing the detected fluid pressure with a predetermined pressure that is conducive to cavitation to determine whether the detected fluid pressure approximates the predetermined pressure;

if detected pressure approximates the predetermined pressure, correlate the detected pressure with vibration to confirm the presence of cavitation.

11. The method of claim **10** wherein the predetermined pressure is vapor pressure for a fluid being pumped by the pump.

12. The method of claim **10** wherein fluid pressure is detected by a pressure sensor proximate a suction manifold of the pump.

13. The method of claim **10** wherein the step of comparing the detected fluid pressure with a predetermined pressure is performed by a processor.

14. The method of claim **10** wherein the step of correlating the detected pressure with vibration further comprises dividing the detected pressure and vibration per revolution of the pump.

15. The method of claim **10** further comprising the step of performing corrective action for corrected cavitation.

* * * * *